Research Note

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A DISCUSSION OF HYGROGRAPHS

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Hygrographs are the only instruments now available for obtaining continuous, automatic records of relative humidity under field conditions. Because they are well manufactured, expensive, and standard meteorological equipment, they are often considered to be precision instruments, which they are not. In fact, if they are carefully checked under field conditions, throughout all kinds of weather, an operator is sure to find them at times quite erroneous. Then he is apt to condemn them. If the causes of such errors are known, however, they can sometimes be avoided or proper allowances can be made. If the instruments' limitations are known and not exceeded, very good results are possible.

Lack of understanding of the causes behind some erratic behavior that had been observed in hygrographs, recently led one forest experiment station to conclude "If accurate records of either daily minimums or of diurnal trends [of relative humidity] are needed, then psychometric readings are necessary."1/

Experience at the Priest River Experimental Forest, Idaho, does not substantiate such a statement. There, during a favorable season, certain hygrographs have been operated within the limits of accuracy with which Samuels,2/ in the following statement, credits the sling psychrometer:

1/ U. S. Forest Service Division of Research, Bi-monthly Report for April 1941, p. 27.

2/ Samuels, L. T. 1925. On the reliability of hair hygrometers. Mo. Wea. Rev. 53:(12)534-535.

"Under the best of conditions, i.e., when both thermometers are accurate, the wet bulb properly covered and moistened, the exposure and ventilation adequate and the temperature above freezing, the humidity measurements from a psychrometer will be accurate within about 2 percent, but if either the temperature or relative humidity is low, or the air approaching saturation, the errors may be larger than 10 percent." According to the above statement, even the sling psychrometer cannot be considered a precision instrument.

Although it has several weaknesses, the hygrograph has a number of advantages over the sling psychrometer which make it more desirable for some uses.

1. It is automatically recording.

2. Where humidity fluctuates rapidly, as under timber on a windy day, the hygrograph tends to average the fluctuations whereas an instantaneous psychrometric measurement may be 5 or 10 percent from the average.

3. Under favorable conditions some are capable of approximating the accuracy of the psychrometer.

4. In subfreezing temperatures a good hygrograph is the more accurate.

5. If two or more hygrographs are calibrated alike, they will generally continue to record alike as long as they are exposed to similar weather. They can therefore be relied upon to measure the difference in humidity between two or more places reliably even when the actual humidity is at times recorded erroneously.

The sources of error in hygrographs that have been encountered at Priest River are (1) "zero shift," (2) range elongation, (3) incomplete anamorphosis of the humidity-sensitive element[3/] curve of relationship to fit a uniformly graduated chart, (4) poor mechanical sensitivity, and (5) chart troubles. Of these, zero shift and range elongation result from characteristics of the sensitive elements, whereas the other sources are mechanical defects.

Zero shift refers to a change in the position on the chart that zero humidity, if encountered, would be recorded. When the zero shifts upward all other humidities are recorded correspondingly high, and when zero shifts downward all other humidities are recorded correspondingly low. This, the most serious source of error in hygrographs, generally accompanies weather changes. During calibration hygrographs are generally exposed, over a period of a few hours, to a series of humidities ranging from near saturation to 30 percent or lower. The exposure to "near saturation" results in a low zero position.

3/ The sensitive elements consisted of human hairs in four of the models tested and of wood fibers fastened to a coiled spring in the fifth model.

Following this calibration, exposure to dry weather accompanied by infrequent saturations causes an upward shift of zero. Subsequent saturations are then accompanied or followed by downward shifts of zero to, or near, the original calibration position. With the return of dry weather the zero gradually rises again to its "fair weather normal."

The drier the weather during "dry" periods, the higher zero seems to shift from its calibration position, hence the greater the downward shifts that take place following storms. During dry seasons shifts of 10 to 15 percent have not been uncommon following marked weather changes on the Priest River Experimental Forest. In 1941, however, the "summer without a drouth" in northern Idaho, one hygrograph exposed under a dense timber canopy performed the whole season without need of resetting and without a single zero shift in excess of 2 percent. The climate under the timber canopy remained definitely humid all summer, the humidity dropping below 30 percent only 15 times for a total of only 39 hours in 6 months.

Such behavior suggests that frequent saturation of the sensitive element might keep the zero in its original calibration position and thereby eliminate zero-shift errors. It is quite certain that by this method such errors can be greatly reduced. According to Spilhaus,[4] "Periodic saturation of the hair with distilled water has frequently been recommended.......as it is found that any shift of the zero of the calibration is corrected thereby ...." Krogh[5] found that saturation should take place at least every third day. Although this practice has not yet been tried at Priest River on hygrographs, it has proven very effective with duff hygrometers (using rattan as the sensitive element) which, because they are exposed to extremes of low humidity and high temperatures, are subject to extreme shifts of zero.

<u>Range elongation</u> apparently results from exposure to low humidities. Krogh credits Gay-Lussac with the statement, "Hairs should not be exposed to degrees of moisture below 20 percent where the reaction is quite slow and the hair may become permanently altered......" "Permanent alteration" in the form of range elongation has proven to be a common occurrence at Priest River. We have found, however, that it may occur without exposure to humidities as low as 20 percent, and that the amount of elongation is related not only to the degree of dryness, but also to the length of time that low humidities endure. Table 1 shows the range elongation of four different hair hygrographs in relation to humidities below 30 percent.

4/ Spilhaus, Athelstan F., 1935. The transient condition of the human hair hygrometric element. Mass. Inst. Tech. Meteorological Course, Professional Notes No. 8.

5/ Krogh, August, 1940. A Micro-climate recorder. Ecology 21(2)225-278.

Table 1.--Range elongation of four different hair hygrographs in relation to humidities below 30 percent. Calibrated in April, checked in November

Exposure	Relative humidity below 30 percent		Pen movement in response to a humidity change of 50 percent	
	No. times	No. hours	April 1941	November 1941
			Chart units	Chart units
Full timbered	15	39	50	52
Part timbered	26	99	50	57
Clear cut	28	96	50	55
Clear cut	5	22	50	52

As is evident, two of these instruments exhibited small elongations of about 2 percent in a range of 50 percent after having experienced below-30-percent humidities for 39 and 22 hours. The other two exhibited moderate elongations of 7 and 5 percent, respectively, after having experienced below-30-percent humidities for 99 and 96 hours. Yet not one of these four instruments experienced humidities as low as 20 percent during the time included. Hence, while the degree of dryness at which range elongation commences is not known precisely, it is believed to be higher than that reported by Gay-Lussac.

The only remedy for range expansion is to make compensating range-shortening adjustments as they become necessary. In humid climates, however, range elongation may not be an important source of error.

Incomplete anamorphosis of the humidity-sensitive element curve to fit a uniformly graduated chart is encountered in some instruments, even when they are in the best possible adjustment. Typical performances of several commercial models when in good adjustment are listed in Table 2. All five model "A" and all three model "B" hygrographs tested transformed the element expansion curve to fit their charts perfectly. Each of eight model "C" and all five model "D" instruments, however, exhibited average errors as indicated. The model "C's" registered too high at the range extremes and too low at mid-range, whereas the model "D's" read too low at the extremes and too high in the middle. Eight model "E" recorders exhibited no curvature and good accuracy up to about 45 percent, but between 45 and 55 percent there was an abrupt loss of accuracy as indicated.

Table 2.--Humidities recorded by several commercial models of hygrographs (or hygrothermographs) when in good adjustment and exposed to different humidities

Instrument	Actual humidity, percent							
	20	30	40	50	60	70	80	90
			Recorded humidity, percent					
Model "A"	20	30	40	50	60	70	80	90
Model "B"	20	30	40	50	60	70	80	90
Model "C"	22	30	$38\frac{1}{2}$	48	58	70	83	98
Model "D"	17	29	41	52	62	72	80	89
Model "E"	19	$29\frac{1}{2}$	$40\frac{1}{2}$	47	$54\frac{1}{2}$	$62\frac{1}{2}$	70	78

Mechanical sensitivity is poor if the force exerted by the humidity-sensitive element is insufficient to readily overcome all friction. The torque exerted in hair hygrographs by the contracting hairs (humidity decreasing) is generally sufficient to overcome all friction, but the small weights which most instruments employ to keep the hairs taut exert but little force to move the mechanism when the hairs relax (humidity increasing). Consequently, friction must be kept at a minimum. All mechanism should be kept loose enough so that no "binding" may occur. Bearings should be kept clean but not oiled, as oil collects dust. Most important of all, the pen pressure on the chart should be kept as light as possible. All the fiber-element hygrographs which were tested exhibited adequate torque with both increasing and decreasing humidity when pen pressure was kept reasonably light.

A hygrograph may be tested for sensitivity by jarring it lightly when the humidity is rising. If the pen records a higher humidity after jarring, the sensitivity is poor.

Chart troubles. Strip-type charts, such as those employed on cylindrical drums, sometimes creep out of position during the expansion and contraction that accompanies large humidity changes. Circular charts that are revolved by a central hub upon becoming damp and sodden during fogs sometimes bind near the periphery and become twisted. Foil-backed, or foil-laminated, paper charts and sheets of pure foil have been used to overcome these difficulties, but are too expensive for general use.

Characteristics of individual models. Models A, B and C were designed and manufactured for meteorological use and to meet U.S. Weather Bureau standards. Models D and E are manufactured primarily for industrial use.

Model A is the nearest to mechanical perfection of any of the models tested. The hair element, in common with all hair elements, is subject to both zero shift and range elongation, but the curvature is entirely eliminated from the humidity-hair length relationship, making the instrument very simple to adjust. When the instrument is adjusted to record correctly at a high and a low value (as 70 and 30 percent), all necessary adjustments have been made and the entire range of humidities is then recorded correctly. Sensitivity is not a problem if the mechanism is kept clean, and chart creepage does not occur.

The hygrograph part of Model B (a hygrothermograph) is like Model A in every respect except for mechanical sensitivity. The pressure of the pen on the paper must be kept very light or sensitivity may be insufficient.

While Model C is a masterpiece of fine materials and workmanship, its highly responsive, spread-hair element is nevertheless subject to zero shift and range expansion. Furthermore, as shown by Table 2, the humidity-hair length curve has not been entirely anamorphosed to fit the chart. When this source of error becomes exaggerated by range expansion, precise measurements are impossible over a wide range. The manufacturer is aware of this deficiency and may correct it soon. Model C has good sensitivity but the strip-type charts have a definite tendency to creep out of position during alternately wet and dry weather. Adjustments to correct for both zero shift and range expansion can be readily made. Excellent and detailed instructions for the calibration and adjustment of model C can be found in the Soil Conservation Service Handbook for Climatologists, part 5, "Instructions for the measurement of evaporation from natural surfaces" by C. W. Thornthwaite, dated June 9, 1939. The manufacturers recommend, however, that the range be adjusted at the 30-70 percent values instead of the 30-90 percent as used by Thornthwaite.

The Model D employs a highly sensitive spread-hair element which is, of course, subject to the common faults of hairs. Compensation for curvature, as shown by Table 2, is not quite complete. Facilities are provided to make adjustments for zero shift and range expansion but satisfactory adjustments are sometimes difficult to make. A change to shorten the range may affect the adjustment of the curve-transforming mechanism, thereby necessitating additional adjustments which may cause trouble if attempted by the inexperienced. The torque developed with rising humidity is very weak so pen pressure must be kept at an absolute minimum, and during foggy weather the charts are prone to twist and wrinkle. Some charts have been encountered which were so large they had to be trimmed at the periphery before they would fit the instrument. This instrument is capable of a quite high degree of accuracy, but requires very careful adjusting and frequent observation.

Model E is of a different type in that it employs a sensitive element of wood fibers around a coiled screen made of spring wire. It is not as sensitive as the hair instruments but that is not necessarily a fault, as it will draw, in rapidly fluctuating humidity, a trace that is the average of the fluctuations. It is subject to zero shift, but range expansion has not been encountered. Its outstanding defect is the peculiar relationship between actual and recorded humidity (Table 2). Up to, and including about 45 percent, it is quite accurate and all curvilinearity is eliminated, but between 45 and about 55 percent there is an abrupt loss of accuracy. Above 55 percent all values are characteristically recorded 5 to 15 percent too low. The coiled element develops a good strong torque and chart troubles are uncommon. Zero shift can be readily adjusted but no other adjustments are provided. This instrument may be likened to a low-cost, fixed-focus, one-speed camera. A neophyte will obtain better pictures with such a camera than with a complex one having many adjusting devices. For work that requires an instrument which will operate with a minimum of care and adjustment and which does not require that humidities above 50 percent be measured accurately, Model E is a good choice.

(For distribution only in the Department of Agriculture)

The hygrographs discussed in Research Note No. 25, "A Disbussion of Hygrographs," are:

Model A. Julien P. Friez and Sons, Inc., Baltimore, Maryland, Model 580. Hygrograph only.

Model B. Friez "double-ender." A model of about 1920-25 hygrothermograph having a humidity element on one end and a témperature element on the other. It bears no model number.

Model C. Friez model 594, hygrothermograph.

Model D. Foxboro "temperature and humidity recorder," bearing no model number but purchased in 1936 and using çhart no. 799413. The Foxboro Company, Foxboro, Massachusetts.

Model E. The Bristol Company, Waterbury, Connecticut, model 4069 temperature and humidity recorder.